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POLYMER COMPOSITES REINFORCED WITH LIGNOCELLULOSIC FIBERS INTENDED FOR THE WIND ENERGY SECTOR: A REVIEW

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Abstract: Considering today's two biggest technical-scientific challenges, that is, the energy transition process and the increasing use of materials in a sustainable and eco-friendly way, this study proposes a review of the main research aimed at reinforced polymer matrix composites with fibers of plant origin aimed at application in the wind energy sector. In order to make this growing renewable industry gradually more competitive, committed to the decarbonization of the atmosphere, sustainability and biodegradability, polymer composites whose dispersed phase is partially or completely composed of lignocellulosic fibers have been widely studied in recent years. Almost completely, wind rotor blades have received more attention, however, in a very recent analysis, promising results were also found for use in horizontal axis wind turbine towers. In summary, multiphase compounds formed by polymers and natural fibers can, in fact, contribute to the growth and optimization of the wind sector, giving it even more competitive advantages compared to other areas of renewable energy and adding even more value and environmental responsibility to it. in a near future.
Keywords: Polymeric Composites, Lignocellulosic Fibers, Wind Generator Components, Wind Energy.

INTRODUCTION

It is a well-known fact that the energy transition process is at an imminent stage and, therefore, the renewable energy sectors need to be more competitive from an environmental and economic point of view. Investing in alternative materials that are sustainable and less harmful to the environment can be a differentiator for industries such as wind power, given that it is one of the fastest growing currently and still has a lot of room for optimization.

According to Kinani et al (2023), replacing steel in wind sector applications would reduce, for example, the amount of CO2 equivalent emitted per unit of energy generated. Therefore, in this situation, there are two possibilities for this industry to become more competitive in this regard, one is to generate more energy and make this relative metric lower or, in fact, to use alternative materials to steel that consume resources in crucial components of wind turbines. responsibly and that are still eco-friendly.

The search for an optimal use of materials in the wind energy sector is not new and in around 80 years, this sector of renewables has undergone numerous transformations, however, the variables of sustainability, biodegradability and decarbonization of the atmosphere are, nowadays, essential to reduce the emission of gases that intensify the greenhouse effect and avoid the depletion of resources for future generations.

Within this context, research is carried out whose general objective is a review of recent literature regarding alternative materials that have been recently studied for the wind industry and, specifically, it seeks to emphasize a bibliographical analysis on polymer composites reinforced with lignocellulosic fibers, taking into consideration, all the advantages they present in relation to the variables listed in the previous paragraph. Furthermore, a reflective analysis of trends and perspectives for the topic is carried out in the final considerations of this study.

DEVELOPMENT

It was only between 1956 and 1957 that a company called SEAS managed to obtain an example of a successful wind turbine, after premature failures with the use of metallic materials in rotor blades during the 1940s in the USA.

Built in southern Denmark, using composite material blades, this turbine had a rotor with a diameter of 24 m, 3 blades, a power of 200 kW and was recorded as the first success story in the area of wind energy, having operated for 11 years. without undergoing maintenance (Mishnaevsky, 2012).

A wind turbine, in general, must operate for 20 to 25 years with minimal maintenance interventions. During this period, the turbine blades must present very small deformations, the effects of fatigue due to rotation and cyclic wind loads must be negligible, in addition to the blades having to withstand extreme static and dynamic loads caused by the winds. As the dimensions of the turbine increase, these structural effects become more relevant and the more complicated maintenance services are (Mishnaevsky, 2012).

Observing all these design requirements, only materials with high strength, very good fatigue resistance and appropriate stiffness can be used in wind rotors. In this context, the class of composites stands out, as no other material satisfies all of these design requirements simultaneously (Mishnaevsky, 2012).

Figure 1: Some wind turbines at the Gargaú wind farm in the north of the State of Rio de Janeiro.

Considering the advantages observed in research that considers the use of fiberglass composite in wind towers (Park, 2018), it is clear that this is a design possibility that has not yet been explored. It is desirable that there be more studies and analyzes focused on this type of application of composites, as it is a topic with little approach in academia and, therefore, a technological field with many gaps in knowledge.

O'Leary, Pakrashi and Kelliher (2019) point to the construction standards of these structures, which are currently mostly produced from steel, however, the wind industry is reaching limits of practicality to establish design methods for these supports and become more competitive. According to these researchers, composite materials, such as: carbon fibers and glass in an epoxy matrix, have been considered optional to steels due to their good structural properties and because they resist degradation processes caused by environmental agents, mainly corrosion in offshore and coastal installations.

This position of the authors mentioned in the previous paragraph, in a way, also encourages and leaves an entire field of studies and analyzes open for alternative composites, in particular, those whose dispersed phase is formed by natural lignocellulosic fibers in search, mainly, of a increasingly greater adaptation to contemporary environmental needs.

THE STATE OF THE ART

Regarding studies on the development of polymer matrix composites with a dispersed phase composed of natural fibers for the wind industry, Shah, Schubel and Clifford (2013) carried out a comparative study between wind blades (compatible with 11 kW turbines) produced with linen/polyester and fiberglass/polyester composites.

The aforementioned researchers found that the component made from natural fiber was 10% lighter than that from synthetic fiber, in line with initial expectations, given the lower density of vegetable fibers. Static bending tests showed that the plant fiber blade meets design and structural integrity requirements for the aforementioned turbine type. As the average bending stiffness of the fiberglass/polyester blade is greater than that of linen/polyester, the authors suggest changes to the stiffening elements of the natural fiber blade to increase its stiffness. Finally, the article describes that blades developed with this alternative material can be suitable structural replacements for fiberglass blades for small turbines.

The capacity to generate electrical energy in wind turbines is directly related to their size, which is why structures have been built with a rotor diameter and tower height above 100 m. Therefore, the aim is to minimize the weight and maximize the turbine's electricity production. In this context, composite materials reinforced by natural fibers stand out, given that in addition to low density, this class of composites is economical and has interesting mechanical properties for this application (Al-Bat'hi et al., 2015).

In their research, Al-Bat'hi et al. (2015) work with a polypropylene composite reinforced with rice straw. Samples containing 10%, 20% and 30% rice straw were produced and mechanically tested in tensile, flexion and impact tests followed by density determination, dynamic analysis and scanning electron microscopy. Finally, the properties of the composites with different portions of natural fibers and with or without the presence of a coupling agent were compared with those of the glass fiber reinforced polymer composite, which is widely used in the structural components of wind turbines.

Al-Bat'hi et al. (2015) concluded that the densities of the composites produced decreased in relation to the increase in the percentage of natural fibers contained in the samples. With regard to mechanical properties, these are improved as the percentage of rice straw in the material combination increases and morphological tests achieved better adhesion between matrix and reinforcement with the addition of the coupling agent. The authors concluded that the composite produced is a good alternative for smaller horizontal axis wind turbine blades.

In research on the properties of polymer composites reinforced by natural fibers for wind turbine blades, the authors Kalagi, Patil and Nayak (2018) present values referring to three different combinations of composite materials, which have the following constituent elements:

- Composite 1 – Epoxy matrix and linen and sisal reinforcements;
- Composite 2 – Epoxy matrix and fiberglass, linen and sisal reinforcements;
- Composite 3 – Epoxy matrix and jute and coconut fiber reinforcements.

After manufacturing and carrying out mechanical tests with the composites described above, the authors obtained the results shown in table 1 below:

properties	Composite 1	Composite 2	Composite 3
Density (g/cm^3)	1,158	1.28	1.2214
Impact energy (kJ/m^2)	22	51.5	20.2
Tensile strength (MPa)	39.22	56.9	37.65
Modulus of Elasticity (GPa)	2,366	3,351	1.5
Flexural strength (MPa)	61.87	89.2	56.97
Flexural modulus (Gpa)	3.48	5.57	2.87

Table 1: Properties obtained for composites 1, 2 and 3 according to the research by Kalagi, Patil and Nayak, 2018.

Based on knowledge of these measurements, the researchers concluded that in addition to being biodegradable, epoxy matrix composites reinforced with natural plant fibers have mechanical properties suitable for application in the wind sector and are potential candidates to replace conventionally used materials (Kalagi, Patil and Nayak, 2018).

The authors Kalagi, Patil and Nayak (2018) also describe that wind turbines have become important components for national energy matrices in recent decades and materials traditionally used in the sector present problems regarding biodegradability (steel, concrete and synthetic composites).

This condition can be mitigated by the use of polymeric compounds reinforced with fibers of vegetable origin. The researchers also argue that this class of composite materials has economic, technical and ecological advantages in relation to synthetic fibers.

In a review article on polymer composites reinforced by natural fibers to be used in wind turbine blades, Thomas and Ramachandra (2018) present conclusions from several other researchers on the topic. These authors demonstrated that a composite material laminated with 30% bamboo fibers has very good mechanical properties and compared it to bamboo and glass fibers in an experimental life cycle analysis, concluding that the material of plant origin is suitable for the requirements. required for the component.

Yuvaraj et al. (2016), produced four hybrid combinations for the dispersed phase containing sisal and glass fiber in an epoxy resin matrix. Here are the composites developed and their proportions:

- Composites 1 – 50% glass and 50% sisal;
- Composites 2 – 45% glass and 55% sisal;
- Composites 3 – 40% glass and 60% sisal;
- Composites 4 – 30% glass and 70% sisal.

The manufacture of hybrid composites involved a mixture of epoxy and hardener in a 10:1 ratio. The sisal fibers were broken into lengths of up to 5 mm and subjected to an alkaline treatment for two hours. They were then washed and dried by exposure to atmospheric air at 39°C. Finally, the results of the mechanical tests showed promising properties with regard to applications in the wind energy sector.

Pradeep et al. (2019) carried out an extensive literature review on the use of contemporary materials in wind turbine blades. According to these authors, the laminate combining bamboo and wood has superior mechanical properties (fracture resistance and fatigue life) compared to laminates made from birch and glass.

Adequate mechanical properties are achieved with 30% bamboo in the laminate. These authors carried out a comparative experimental analysis between the performances of fiberglass and bamboo wind blades, the researchers suggested that the natural material satisfies what is required for wind turbine blades.

According to pioneering research developed by Machado (2024), epoxy matrix composites reinforced with medium and high theoretical volumetric fractions of ramie fabric (40%, 50% and 60%) proved to be promising and with satisfactory structural capabilities from a theoretical point of view for be applied to wind turbine towers, taking into consideration, the maritime and coastal scenarios typical of Brazilian regions with good wind potential.

It is even highlighted, in the research by Machado (2024), that despite the good structural indicators obtained with the

modeling proposed in principle, some more specific analyzes still need to be explored. There was also another reservation regarding the use of protective coatings against the weather if a wind tower prototype is developed in the future with the aforementioned composite material.

FINAL COMMENTS

Based on the entire review, it can be noted that the use of multiphase materials with a polymer matrix and a dispersed phase made up of natural fibers of plant origin have proven to be possible candidates for bringing greater competitiveness and even cleaner and more environmentally friendly energy generation. responsible for the wind industries.

From approaches made in the previous decade to the most recent ones, wind turbine blades were largely prioritized as the component where polymer composites reinforced with natural fibers would be applied. However, a gap in technical-scientific knowledge was recently filled with an innovative analysis aimed at the use of the composites in question in horizontal axis wind turbine towers.

All the promising proposals summarized in this research open up broad opportunities and trends for a sector that is on the rise, that is, the expansion of wind generation can be accompanied by greater sustainability, reduction of harmful emissions to the environment and biodegradability, facts that they not only assist in the urgent energy transition, but also reduce the high rates of consumption of conventional resources, preserving them for future generations.

Whether with hybrid arrangements or fully made up of reinforcements of vegetable origin, the truth is that multiphase polymeric materials based on this concept can, as proven, help the wind industry in expanding and consolidating in the face of today's two biggest global challenges: the energy transition and the use of materials with greater sustainability.

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